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# Minimization of off-grade production in multi-site multi-product plants by solving multiple traveling salesman problem

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ABSTRACT

Continuous multi-product plants allow the production of several products (product grades). During grade transitions off-spec products are produced. The economic losses and the environmental impact of these transitions are sequence dependent, so the amount of off-grade products can be minimized by scheduling the sequence of the production of different products. Applying parallel production sites increases the flexibility of multi-product plants. Since market demands are changing, the production cycles of these sites should be re-scheduled in certain intervals. Therefore, our task is to design production cycles that contains all required products by minimizing the total length of grade transitions. Most production scheduling problems such as the one considered in this paper are NP-hard. Our goal is to solve realistic problem instances in no more than a couple of minutes. We show that this problem can be considered as a multiple traveling salesmen problem (mTSP), where the distances between the products are based on the time or costs of the grade transitions. The resulted mTSP has been solved by multi-chromosome based genetic algorithm. The proposed algorithm was implemented in MATLAB and is available at the website of the authors (Abonyi). For demonstration purposes, we present an illustrative example. The results show that multi-product multi-site scheduling problems can be effectively handled as mTSPs, and the proposed problem-specific representation based genetic algorithm can be used in wide range of optimization problems.



## 1. Introduction

Thanks to the increasing need for flexible processing facilities to produce more than one product, the planning problem of multi-product plants is becoming more and more important. The planning of process systems involves the procedures and processes of allocating the available resources and equipment over a period of time to perform a series of tasks required to manufacture one or more products. Typical example for such problem is the optimization of the transformation of biomass to energy. Biomass is usually locally available, which defines it as a distributed resource, and requires extensive infrastructure networks for harvesting, transportation, storage, and processing. The design and management of biomass supply chains should account for the local conditions and constrains, such as the existing infrastructure, geographical features of the studied region and the competition among several consumers. Biomass can be wood or forestry residue, energy crops, various kinds of straw, as well as bio-waste from food production, or from wood processing. Primary biomass resources are distributed over the area in a region and often available in remote locations. Building the infrastructure to transfer biomass energy over longer distances would tend to increase its cost. On the other hand, biomass offers the potential to reduce the environmental impact of energy supply and potentially saving costs for reacting to natural disasters in the future. An important factor to be considered is the security of energy supply, which has significant importance (Nagy, 2009; Klemeš and Lam, 2009). Energy generation from domestic sources helps reducing the dependence on foreign imports of crude oil and natural gas. It increases the economic stability and can improve significantly the foreign trade balances of the respective regions and countries. The relatively low energy density (energy per unit volume) of most raw biomass feedstocks tends to increase the cost, emissions and complexity of supply chain. Therefore, the developments of complete procedure

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for regional energy supply optimization become an important task (Čuček et al., 2010).

The goal of this paper is the development of a production planning and scheduling algorithm for parallel (multi-site) continuous processes in the presence of sequence-dependent switchover times. In most cases scheduling problems are addressed for single production centers or specific areas of responsibility. If we look at enterprises that produce at different production sites and must transport intermediate products between two locations, we have to consider new aspects that are to be solved by an adequate approach (Sauer et al., 1998).

In this paper we assume the production of these plans are independent, so there are no complex interdependences between production processes that are performed in different plants. However, the costs of transportation the row materials to the different production sites and the final products to the distribution centers could significantly differ.

The plants are multi-purpose plants, i.e. plants with machines or reactors that can be operated in different modes. In each mode it is possible to produce several products. To switch between modes, a changeover is necessary, which results in a considerable loss of production time. Planning problems of this type, where the production of an item implies some discrete event, are called lot sizing problems(Timpe and Kallrath, 2000). A similar problem is already studied in Kopanos et al. (2011), while a very similar production and distribution industrial problem is presented in Kopanos et al. (2012). TSP is already a widely applied technique for scheduling of parts in a flowshop, for lot of streaming and scheduling problems, and for optimization of robot movements in automated production cells. According to Bagchi et al. (2006), most of real-life problems can be defined as a flowshop, where each machine performs a single operation, and the sequence of the procedures is fixed. Bagchi et al. give a novel classification of these problems, the most important for us is the so-called "group-scheduling", where products belong to different groups and optimization is performed in a two-stage method. The approach is similar to the "manufacturing cell" problem, where similarity coefficients to group similar parts into families. The problem is almost identical to the one we will discuss in the next sections, however, our method is capable to optimize the production process in one step and considers not only the characteristics of manufacturing. Similar problems appear also in shop-floor logistics systems, which influences not only the production control's performance, but the order management and production system also (Gyulai et al., 2013). A TSP-based model for medium-term planning of a single-stage plant with a single continuous processing unit producing several products with sequence-dependent changeovers has been already studied in Liu et al. (2008). There a MILP model is defined for a single-stage plant with a single continuous processing unit producing several products with sequence-dependent changeovers. Though we deal with a multi-site, multi-product processing procedure, our objective is very similar, to maximize the profit, i.e. to minimize product changeover cost which occur when switching from one product to another. We will give a linear programming formulation also in the next sections, and our representative example is also derived from the work of Liu et al. Based on this classic formulation of traveling salesman problem (TSP), an improved model is developed, where the objective function considers the profit, inventory deviations and price changes simultaneously. In our case, inventory deviations are caused by market demand for the various products, and the main goal is to end up final products to the nearest market, i.e. to provide optimal production plan and warehousing for production sites considering product diversification and logistics. As Liu et al. discussed in (2012), if the production changeovers depend on the production sequence, and product groups are involved, the production sequence may affect the capacity of the factory. Therefore, handling the sequence-dependent changeovers is an important issue. The problem becomes more complex when a multisite production system is needed to be optimized. Such production-distribution network is made up of several production sites distributing to different markets. The planning and scheduling model has to include spatial scales that go from a single production unit within a site to a geographically distributed network (Terrazas-Moreno and Grossmann, 2011).

Since economic competition is growing rapidly, companies are greatly interested in reducing overall costs, including manufacturing, inventory, changeover expenses, as well as minimizing ecological footprint and waste production. Therefore, the Enterprise-wide Optimization (EWO) has become a major objective not only in the chemical industry. As Grossmann describes in (2012), EWO is concerned with the coordinated of the operations in supply chain, and the main objective is to maximize profits, responsiveness and asset utilization and to minimize costs and ecological footprint. Therefore, a complex cost function is needed, while complexity should remain as low as possible. We will discuss a compound objective function derived from the utility theory. Recently, very good reviews has been published, dealing with the environmental impacts of emplacement and allocation as well as the optimization according to the available resources and raw materials (Boix et al., 2014). Lin et al. in (2014) discuss the increasing and close attention of green logistics, since the recent production and distribution strategies are not sustainable in the long term. These processes are sensitive environmentally, ecologically and socially, and therefore, it is particularly important to optimize them cautiously.

In this paper we propose multiple-Traveling Salesman Problem based representation for the optimization of multiproduct and multisite production systems, where the distances between the products are based on the time or costs of the grade transitions. The resulted mTSP has been solved by multi-chromosome based genetic algorithm. The chromosome representation and especially the applied operators make our modified genetic algorithm especially effective in the optimization of mTSP problems (Király and Abonyi, 2015). Furthermore, taking additional constraints into consideration, like the maximum number of salesmen or the maximal time a salesperson can travel makes it capable to solve complex structures and in production planning to prevent a single site from overloading. The proposed algorithm was implemented in MATLAB and available at the website of the authors (Abonyi). For demonstration purposes, we present an illustrative example from the literature, which is from a real world polymer processing plant and discussed by Liu et al. (2008). In this simple example we present the optimization of the production of 10 products by 3 sites, using our genetic algorithm based mTSP solver.

## 2. Problem formulation

As we discussed in the introduction, production scheduling problem usually handled by integer programming methods, like MIP (mixed integer programming) or MILP (mixed integer linear programming). In case of complex optimization problems, formulating the problem by MIP and MILP is extremely important, since these formulations are proved to be very effective. Timpe and Kallrath (2000) shows a good example for multi-site and multi-purpose scheduling problem. Although in this paper we do not use a MIP or MILP solver directly, we feel very important to formulate our problem in this way also.

The problem can be illustrated by a schematic diagram, like the one in Fig. 1.